Alberta ENERGY
Research and Technology Branch

The Feasibility of Energy-from-Waste Incineration in Alberta

A project supported in part by the Alberta/Canada Energy Resources Research Fund

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Research and Technology Branch of Alberta Energy.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page nine.

The Feasibility of Energy-from-Waste Incineration in Alberta

The notion that municipal solid waste can be incinerated and converted to the thermal energy needed to produce steam for heating or to generate electricity is hardly new. Many cities in Japan and several European countries have been doing this routinely for decades through large plants capable of handling a minimum of 1 000 tonnes a day of garbage. During the past 15 years, the idea has become popular in the United States, too. It has been estimated that approximately 200 energy-from-waste incinerators are either planned, under construction or operating in the U.S.; 35 of these are designed to burn more than 1 500 tonnes a day.

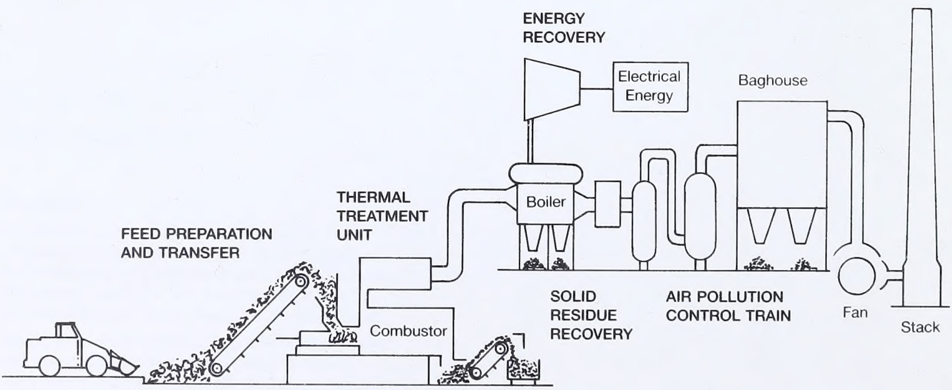
In Canada, however, the concept has been slow to catch on, partly because incinerators are expensive to build and operate, and partly because Canada has fewer large cities in which such facilities are normally located. Nonetheless, many energy and environmental specialists believe that waste incineration represents an improvement over the waste landfilling methods used commonly throughout Canada, especially the practice of open dumping that still persists in many parts of the country.

Therefore, it seemed reasonable to wonder whether recovery of energy from wastes is practical for small communities, such as those in Alberta, the other western provinces and Atlantic Canada. Although some manufacturers claim to make energy-recovery equipment suitable for small amounts of waste, the cost effectiveness of using these quantities to generate energy remains unclear. Consequently, the Alberta/Canada Energy Resources Research Fund (A/CERRF) supported a state-of-the-art review of energy-from-waste technology and the feasibility of its use on a relatively small scale in Alberta. This investigation was carried out during 1988/89 by Dr. R.A. Ritter, a consultant with Western Research of Calgary.

Background

In the U.S., 30 to 40 new waste incineration plants are built each year. It is projected that by the year 2000, 40 per cent of all municipal waste in the U.S. will be processed in energy-from-waste facilities. This compares with approximately five per cent today. In Europe, 300 energy-from-waste incinerators are operating at present, while in Japan, 360 of 2 000 incinerators recover energy from waste. In Canada, meanwhile, fewer than a dozen municipal energy-from-waste incinerators exist.

Elements of an Energy-from-Waste Plant



(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Design Elements

All modern energy-from-waste systems comprise five elements:

- feed preparation and transfer;
- thermal treatment;
- solid residue recovery;
- air pollution control; and
- energy recovery.

While each of these plays a vital role in the overall system, and is discussed in turn in the project report by Western Research, the heart of any energy-from-waste system is the thermal treatment unit. Regardless of the particular configuration of the equipment, all incineration systems employ one of two operating principles: controlled air combustion or excess air combustion.

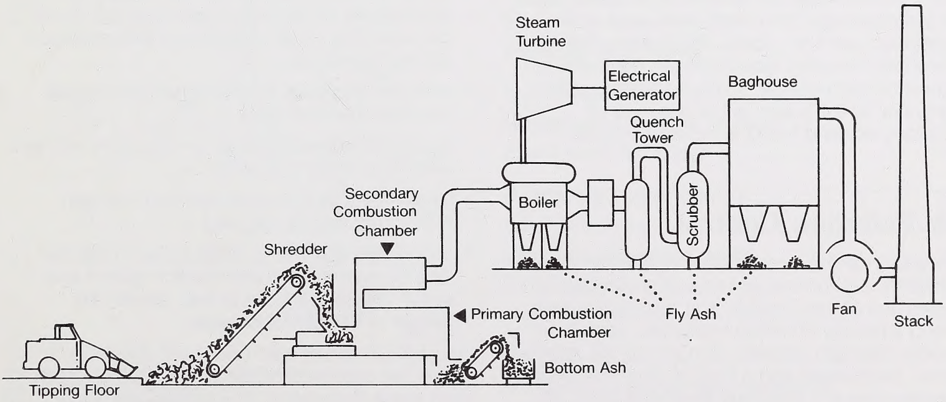
In controlled air systems, less air than is required to completely oxidize all combustible material is introduced into the combustion chamber. Frequently, as little as 60 per cent of the required amount of air is used. This results in a process that can be operated at lower temperatures than one employing 100 per cent of the required air, but it also produces substances that could be harmful if released to the environment. Therefore, controlled air systems must use a secondary combustion chamber into which excess air is introduced to complete the oxidation process begun in the initial combustion chamber. Systems based on this principle produce low concentrations of regulated emissions, and are often able to satisfy current air quality requirements without the need for add-on pollution control equipment.

In contrast to controlled air designs, those employing the principle of excess air allow more air to be introduced than is required to effect complete oxidation of all combustible substances. Although earlier incinerator designs attempted to achieve their design objectives using only one combustion chamber, modern incinerators use either a secondary combustion chamber or a portion of the primary chamber specially configured to serve the same purpose as a secondary chamber.

In addition to being categorized according to the combustion principles used, incinerators are also classified according to certain approaches used in their construction. Thus, most incinerators are either mass burn units or employ modular construction techniques. In both types, wastes are simply loaded into a combustion chamber and burned, without any pre-treatment. Where they differ is in the ease and cost of construction. Mass burn units are more suitable for large operations and are erected on site. They have been built to accommodate up to 3 000 tonnes a day of waste.

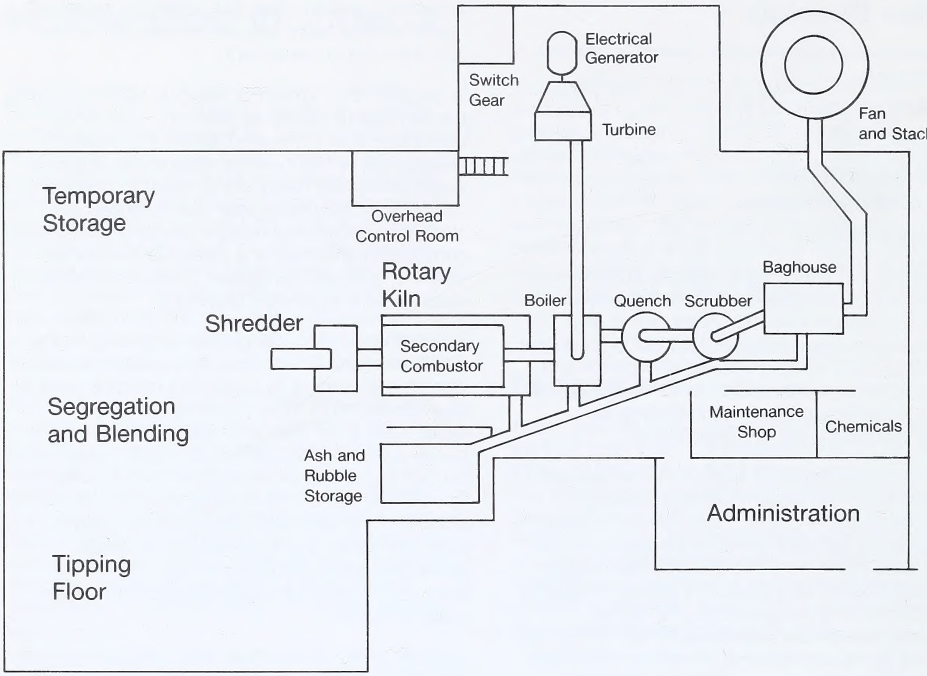
Modular units, on the other hand, are fabricated in a factory and then transported to the incinerator site and assembled. This approach is suited ideally for the units likely to be needed in small communities.

Energy-from-Waste Process Flow Sheet



(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Waste Treatment Centre Plot Plan



(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Incinerator designs that are modular in nature include moving grate furnaces, moving hearth and fixed hearth types, rotary kilns and fluidized bed units. Each of these has its own set of advantages and disadvantages, and some have seen more widespread use than others. Regardless of their differences, however, one of the key measures of incinerator performance, and acceptability of an incinerator by the public, is the quality of air emissions expelled from the incinerator stack.

Air Pollution Control

Flue gases leaving the combustion chamber of an incinerator are normally composed of nitrogen, oxygen and carbon dioxide, and may also contain varying amounts of carbon monoxide, sulphur dioxide, hydrogen chloride, nitrogen oxides, mercury vapour, particulates and a host of other chemical species present in extremely small quantities. To control the release of any of these substances to levels deemed to be acceptable to regulatory agencies, it may be necessary to use several types of air pollution control devices, singly or in combination. The most common devices are:

- flue gas coolers, used to reduce the flue gas temperature low enough to allow the gas to be processed by the air pollution control equipment without harming it;
- acid gas scrubbers to remove sulphur dioxide and hydrogen chloride;
- particulate removal devices to capture fly ash and limit heavy metal emissions;
- various devices to accumulate and transport bottom ash and fly ash; and
- an induced draft fan to maintain the incinerator and the entire air pollution control system at a slight negative pressure to help contain the release of objectionable gases.

Specialized devices also have been developed to collect the solid bottom ash and fly ash residues from waste incineration. The bottom ash is inert and can be deposited directly in a properly designed and operated sanitary landfill, but fly ash

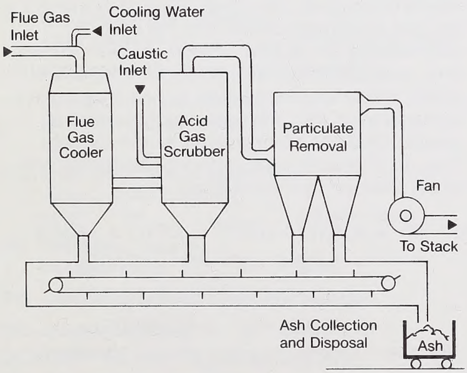
is sometimes contaminated with unacceptable levels of hazardous substances. This may require some special handling, but nothing beyond procedures already well established.

Emissions

Although the type and concentration of chemical substances in air emissions from waste incineration plants are determined by the nature of the waste itself, modern analytical technology is capable of detecting each of these species at concentration levels substantially below detection limits of only a few years ago. While this ability is of considerable importance in controlling the release of emissions to the atmosphere, it has also generated a controversy because some of the detected substances are known to be toxic in certain concentrations. Thus, any proposal to establish an incinerator in a community often encounters opposition from the public. However, the fact that all substances may be controlled at concentrations well below those having any known effect on humans is often overlooked by those who oppose waste incineration.

A case in point concerns the production of dioxins by waste incinerators. Several members of this group of toxic chemical compounds are produced by incinerators, but attempts to measure their concentration at ground level near incinerators have shown they are present in lower concentrations than the normal background level of dioxins in the soil.

Air Pollution Control Train



(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Similar conclusions have been reached from risk analysis studies. This is a way of comparing the effects of various activities on human health. Risk is usually expressed in terms of incremental increase in the number of deaths from a specified cause occurring in a population of one million people exposed to a hazard for 24 hours a day over a 70-year life-span.

Living near an energy-from-waste plant was assigned a risk factor of 10, versus risk factors of 252 000 for cigarette smoking, 13 900 for motor vehicle accidents, 7 700 for accidents in the home, 560 for eating four tablespoons a day of peanut butter, and 35 for being struck by lightning. Living near a municipal landfill was given a rank of 300.

Comparative Health Risk Assessment

Activity and Lifetime Risk (70 year) per Million Population

Cigarette smoking	252 000
All cancers	196 000
Mining and quarrying	66 500
Construction	42 700
Mountain climbing	42 000
Agriculture	42 000
Police on duty	15 400
Air pollution (eastern U.S.)	14 000
Motor vehicle highway accident	13 900
Police on duty killed by felons	9 100
Home accidents	7 700
Service and government	7 000
Manufacturing	5 740
Frequent air travel	3 500
Pedestrian hit by vehicle	2 940
Alcohol, light drinker	1 400
Background radiation at sea level	1 400
Peanut butter (60 ml/day)	560
Drinking chlorinated water	460
Electrocution	371
Living near a municipal landfill	300
Tornado	42
Lightning	35
One X-ray	20
Living near an energy-from-waste plant (typical worst case)	10
Earthquake (southern California)	1.0
Smoking 1.4 cigarette/day	1.0

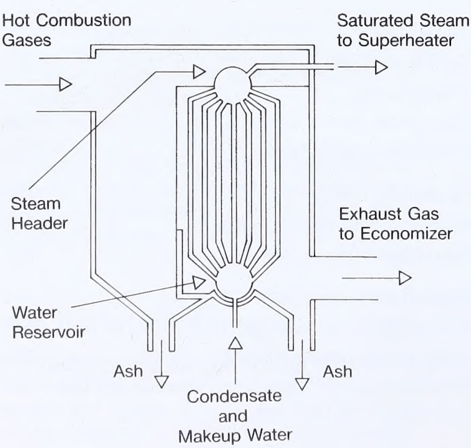
Drinking 0.5 litre of wine	1.0
Canoeing for 6 minutes	1.0
Bicycling 16 km	1.0
Car travel for 48 km	1.0
Jet plane travel for 1 600 km	1.0
Cosmic ray exposure in jet plane for 9 600 km	1.0
Drinking water with trichloroethylene at EPA limit	0.14

(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Energy Recovery

The first step in recovering energy from waste is to produce steam, regardless of whether the ultimate objective is to generate electricity or to supply energy for a hot water heating system. Steam is produced when hot flue gases from the secondary combustion chamber come in contact with water-filled metal tubes inside a boiler. If the steam is to be used to generate electricity, it is passed through a heat exchanger to achieve a temperature of 300°C to 400°C, and then it is delivered to a power-generating turbine. Alternatively, the steam can be used directly in a steam-heating system. Normally, this is done by transporting the steam through pipes to nearby customers. Usually, it is not practical to pipe the steam over distances exceeding one kilometre. Experience has shown that the energy efficiency of converting waste to steam is approximately 50 to 70 per cent, while it is only 20 to 23 per cent for conversion to electricity. Under some circumstances, both steam heating and power production can be accomplished from the same energy-from-waste plant. This concept, known as co-generation, is more energy efficient than either steam heating or electricity generation alone.

Vertical Tube Boiler



(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Economics

A mathematical model expressing the various elements contributing to the economics of energy-from-waste incineration was developed for this project. In its simplest form, this relationship can be expressed by the following equation:

$$TF = TC + DC - TR$$

where

TF is a subsidy called a tipping fee paid by, or on behalf of, users;

TC is the waste collection and transportation cost;

DC is the total cost of disposition of the waste; and

TR is the total revenue generated through recovery and sale of material and energy.

Although TC, representing collection and transportation costs, is fairly straightforward, the other elements of the equation are somewhat more complex. For example, the disposition expenses include the costs to purchase the site, the capital costs of plant construction, the plant operation and maintenance costs, the costs to landfill incinerator ash and non-combustibles, and the costs of administering the system. Similarly, in their simplest form, revenues comprise income from the sale of steam, power and recyclables, but each of these elements must take into consideration a host of variables that can be expressed mathematically. Thus, the following expression was advanced for a facility financed by a bond issue:

$$\begin{aligned} TF - TC = {} & (IC/D)\{(1+i/n)^{(n)(y)} + (OF)(L) + (AF)(L)\} \\ & + (NR)(NF+BF+FF) + (FF)(CS) \\ & - ((HC)(FC)(CE))\{((FS)(1-FL)(PS))/(SE) \\ & + (FE)(EE)(PE)\} - (1-FC-NF)(RS) \\ & + ((PC)\{((QS)(C)(DL))^{0.6}\}(1+i/n)^{(n)(y)})/((DC)(C)). \end{aligned}$$

A separate equation was developed for mortgage financing.

Nomenclature Summary

AF	Administrative cost as a fraction of total capital costs	
BF	Bottom ash fraction	tonnes/tonne waste
C	Plant design capacity	tonnes/day
CE	Energy conversion efficiency for heat to steam	
CS	Surcharge component for flyash monofill	$/tonne
D	Projected plant operating life	days
DC	Total waste disposal costs	$/tonne waste
DL	Cumulative length of steam delivery lines	
EE	Energy conversion efficiency for steam to electrical power	
FC	Fraction of waste stream incinerated	
FE	Fraction of total energy sold as electrical power	
FF	Fly ash fraction	tonnes/tonne waste
FL	Fraction of steam lost in transmission	
FS	Fraction of generated steam for direct sale	
HC	Heat content of waste incinerated	mJ/tonne waste
IC	Unit plant plus site capital cost	$/tonne waste/day
L	Projected plant operating life	years
NF	Non-processable fraction of waste received	tonnes/tonne waste
NR	Sanitary landfill charge rate	$/tonne
OF	Operating and maintenance cost as a fraction of capital cost	
PC	Total capital cost of steam delivery system per unit length of line	$/tonne waste
PE	Unit selling price of electrical power	$/mJ
PS	Unit selling price of steam	$/tonne
QS	Quantity of steam purchased	tonnes/tonne waste
RS	Weighted average selling price of recovered materials	$/tonne
SE	Enthalpy of steam	mJ/tonne
TC	Waste collection and transportation costs	$/tonne waste
TF	Tipping fee	$/tonne waste
i	Bond or mortgage annual interest rate	%/100
n	Number of interest-compounding periods per annum	
y	Bond term	years

(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

With either formula, it can be shown that a typical energy-from-waste incinerator cannot generate sufficient revenue from the sale of steam, power or recyclables to cover its costs. Therefore, it must be subsidized through tipping fees. For example, using reasonable costs for a small incinerator designed to handle 50 tonnes a day of waste, and operating under realistic, but hypothetical, conditions and having sales of steam for both power and heating, it was shown that a tipping fee of approximately $52 a tonne would be required.

To make this a more meaningful exercise, an actual case study was undertaken for the County of Mountain View in central Alberta. Specifically, it considered a facility to incinerate municipal wastes produced within a radius of 50 kilometres of the town of Olds. This location was chosen because the area currently is experiencing a critical waste disposal problem.

The case study considered the current population and appropriate waste generation and cost figures for the area. It was assumed the design capacity of the incinerator would be 50 tonnes a day, and all the steam it produced would be used to generate power. The electricity would then be sold to the local utility under provisions of the Small Power Research and Development Act. This would generate a minimum income of 5.2 cents per kilowatt hour. Also, the facility would be equipped with appropriate technologies for monitoring and controlling all gaseous, liquid and solid by-products.

An economic analysis was performed to determine the magnitude of the tipping fee required to ensure financial solvency of the facility under four possible situations:

1. capital financing by a 10-year loan, and plant management through a second party contract;
2. capital financing by a 10-year mortgage, and plant operation and management by municipal employees;
3. capital financing by an interest-free loan, and plant operation and management by municipal employees; and
4. capital financing through a grant, and plant operation and management by municipal employees.

Thus, the tipping fees calculated for the four situations ranged from $74.97 in the first case to $5.68 in the fourth. The analysis found that several elements were cost sensitive:

- the tipping fee was most sensitive to the method of financing;
- basic operating costs represent a significant portion of total expenditures. It is not likely they can be reduced;
- management fees can be reduced substantially by using municipal employees. This has some disadvantages if experience is important;
- ash landfill costs contibute only marginally to the total costs. There is little to be gained from concentrating on this as a possible source of cost savings; and
- the revenue from the sale of electrical energy is a vital element in establishing the economic viability of energy-from-waste plants. In the second situation, revenues derived from energy recovery reduced the tipping fee to $31/tonne. This is identical to the costs incurred at the time of the study by the town of Olds to ship wastes to a landfill in Calgary. Also, it would provide a permanent solution to the problem, whereas transporting wastes to another community is likely only a temporary solution.

Tipping Fee Estimation for Four Scenarios*

Scenario	1	2	3	4
Capital Cost	48.24	25.60	15.04	–
Operating Cost	24.07	24.07	24.07	24.07
Management Cost	27.07	6.02	6.02	6.02
Landfill Cost	4.10	4.10	4.10	4.10
Total Cost	103.48	59.79	49.23	34.19
Revenue	28.51	28.51	28.51	28.51
Tipping Fee**	**74.97**	**31.28**	**20.72**	**5.68**
Annual Per Capita Cost	44.98	18.77	12.43	3.41

* All quantities expressed in Canadian dollars/tonne.

**The tipping fee quoted is exclusive of waste collection and transportation costs.

(Source: An Evaluation of The Waste-to-Energy Concept and Its Application in Rural Alberta, Ritter, R.A., Western Research, September 1989)

Conclusions

Properly designed and operated sanitary landfills have served a useful purpose in allowing waste disposal practices to progress rapidly during the past 20 to 30 years, and they clearly represent an improvement over the practice of simply discarding wastes in open dumps and ignoring them.

Nonetheless, as current landfills become full and communities face increasing public pressure to provide low-risk methods of waste disposal, energy-recovery incineration will likely occupy an expanding niche in the array of waste managment options. This is not to say that incineration is completely free of issues and concerns, but neither is it accompanied by insurmountable problems.

One of its advantages is the potential to recover valuable material and energy resources. When integrated into a waste management policy that includes resource recovery by processes such as composting and recycling, energy-from-waste incineration could reduce substantially the need for the less-desirable alternative of landfilling without pre-treatment.

Also, the advent of modular energy-from-waste technology has made it possible to process 50 tonnes a day or less of waste and still achieve reasonable economics. Moreover, such systems can be equipped with the most advanced emission control technology. Thus, residents of small, rural communities can enjoy the same waste management advantages as their big city counterparts.

As compared to landfilling, the risks associated with waste incineration are lower and they are more likely to be confined to the present, whereas the legacy of landfilling may last a long time.

In terms of cost, it is reasonable to expect that a suitable energy-from-waste system can be operated in small centres for an annual per capita cost of approximately $30. This is almost insignificant when compared to the costs of other services provided by municipalities.

Finally, the study concluded that adoption of energy-from-waste technology for use in small communities is both timely and practical, and that Alberta would be well advised to pursue it vigorously.

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